Ariane Launch Window: James Webb Space Telescope

Kevin Langone, 2003 NASA Goddard
Academy Research Associate
Department of Aerospace Engineering
Virginia Tech, Blacksburg, VA

Principal Investigator: Mark Beckman
Flight Dynamics Analysis Branch, Code 595
NASA Goddard Space Flight Center, Greenbelt, MD

The Project

Knowing the Ariane 5's launch parameters, it is instructive to see when during the year (the launch window) would be optimal to launch JWST. The spacecraft will be placed into a large orbit about the Sun-Earth L2 point (an unstable equilibrium point in the Sun-Earth/Moon system) known as a halo orbit. JWST requires an extremely cold (<30 K) environment to operate its optical instruments. L2 provides an ideal place for it to orbit, as the Sun, Earth, and Moon are always in the same direction, allowing JWST to block much of the incoming light with its sunshade. The advantage of the large-amplitude halo orbit is that it prevents eclipses and reduces fuel costs on transfer (as compared with an orbit at L2). Thus, the orbit is calculated for each day of the year, and certain results are extracted for comparison. Mission requirements dictate a minimum ten year lifetime with no eclipses; the times of year when this condition is satisfied are to be determined. In addition to all the data listed in the "Parameters of Interest," complete eclipse reports and the complete satellite file for each day are saved for future use (e.g. to examine a new data element).

Why the Ariane 5?

The status of the shuttle fleet makes its reliability as a launch option uncertain, and the spacecraft's mass (~5400 kg) excludes many expendable launch vehicles. The Ariane 5 ECA heavy payload vehicle offers a potential solution.

Ariane 5 Launch Parameters

-Launch from Kourou, French Guiana
-Eastward launch towards Africa
-Inclination 12.7 degrees
-Right Ascension of Ascending Node: 157 degrees
-Argument of Perigee: 203.8 degrees
-Perigee Altitude: 306 km

Computational Tools

-Satellite Tool Kit (Astrogator): orbit propagator and   differential corrector (allows construction of theoretical orbit)
-STK Connect: allows user to send text commands to STK through an outside program
-Matlab: script file sends Connect commands (provides reusability) and assembles/plots data of interest

The Model

-Perigee time 12:30 GMT each day of 2011
-Propagate orbit for ten years
-Sun, Earth, and Moon provide gravitational forces
-Solar radiation pressure included in propagator
-No launches when moon is in the way
-Target perpendicular crossings to create symmetrical orbit

Parameters of Interest

-Sun Angle
-Moon Phase
-Perigee Velocity
-C3 Energy
-Ecliptic Inclination
-Perigee Right Ascension
-Perigee Declination
-Time of Flight
-Max Y Amplitude
-Max Z Amplitude
-Minimum Elongation Angle
-Maximum Elongation Angle
-Orbit Class
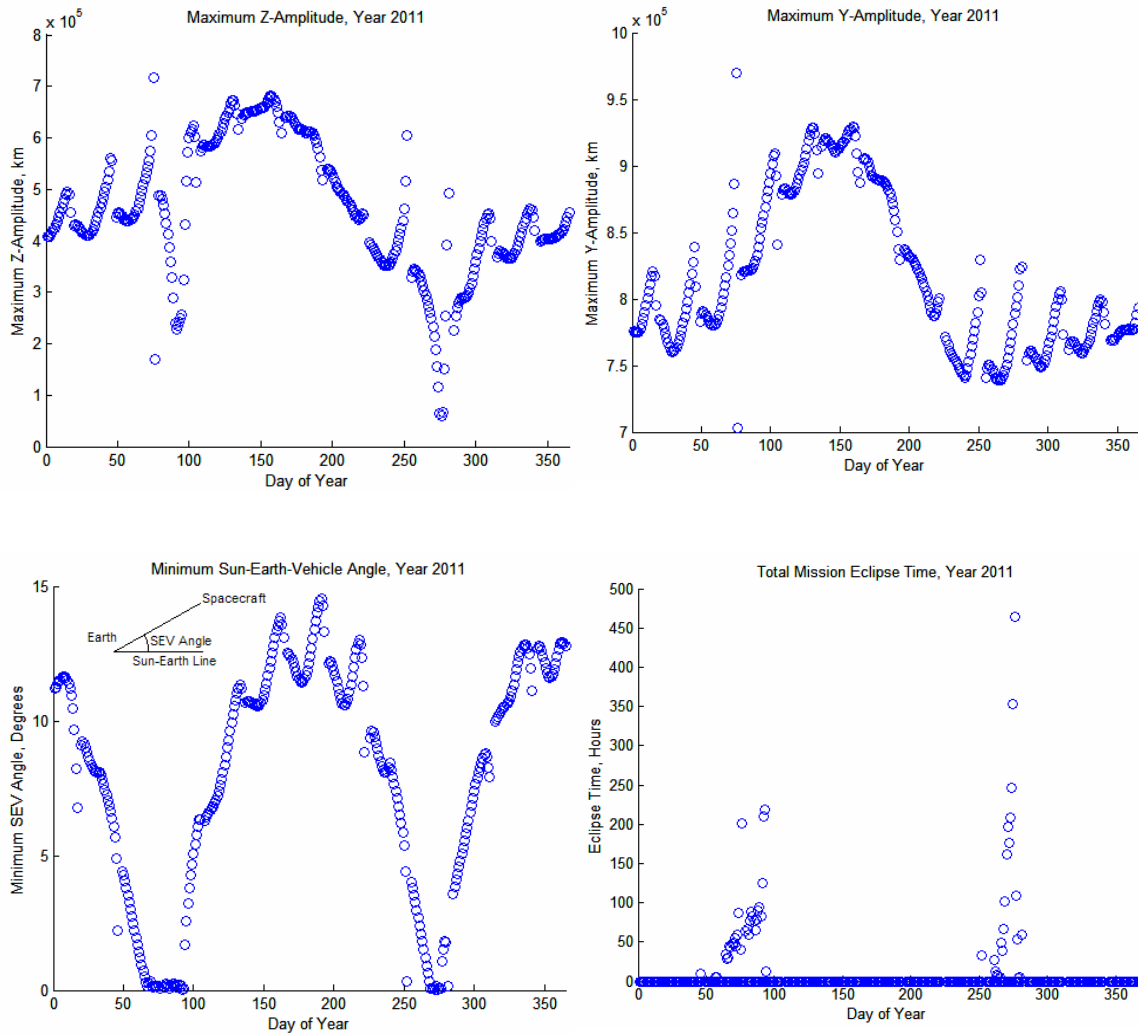-Radius of Apoapsis
-Total Eclipse Time
-Number of Eclipses

Sample Matlab Code

```
command=[getResultsbase 'Propagate'];rtn=stkExec(conID,command);
[t,r]=strtok(rtn(2,:));[t,r]=strtok(r);[xpos,r]=strtok(r); xpos=str2num(xpos);
if xpos<-600000
command=[setValuebase 'Target_Sequence' num2str(i)
'.Profiles.Targeting_Profile.Results.Vx.Desired .015 km/sec'];
stkExec(conID,command); command=['Propagate ' Sat ' ' startDate ' ' stopDate];
stkExec(conID,command);
command=[getMCSbase 'Target_Sequence' num2str(i) '.Profiles.Targeting_Profile
Impulsive_Maneuver Cartesian.X Correction'];
```

```
rtn=stkExec(conID,command); [val,units]=strtok(rtn); vxcor=str2num(val);
command=[getMCSbase 'Target_Sequence' num2str(i) '.Profiles.Targeting_Profile
Impulsive_Maneuver Cartesian.X Nominal'];
rtn=stkExec(conID,command); [val,units]=strtok(rtn); vxnom = str2num(val); vx=vxnom+vxcor;
command=[setBurnbase 'Impulsive_Maneuver.Cartesian.X ' num2str(vx,25) ' km/sec'];
stkExec(conID,command);
command=[setMCSbase 'Target_Sequence' num2str(i) '.Profiles.Targeting_Profile
Impulsive_Maneuver Cartesian.X Correction 0 km/sec'];
stkExec(conID,command);
command=[setValuebase 'Target_Sequence' num2str(i)
'.Profiles.Targeting_Profile.Results.Vx.Desired 0 km/sec'];stkExec(conID,command);
end
```
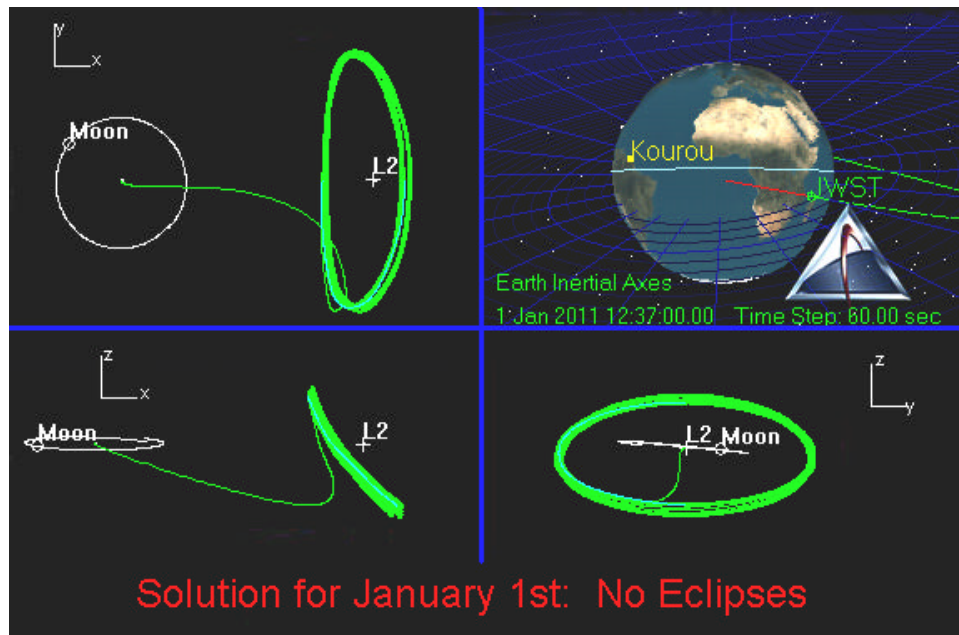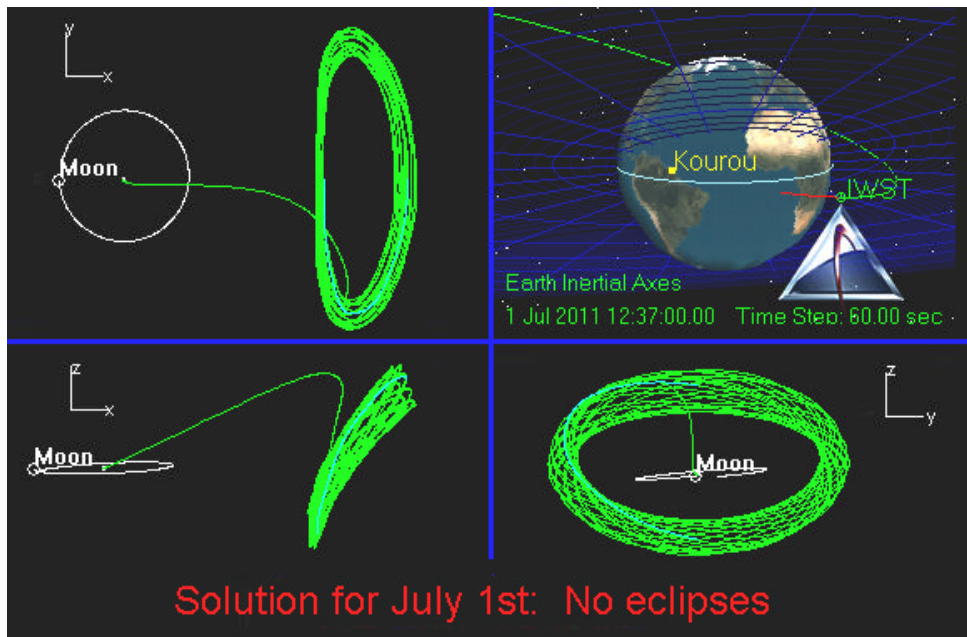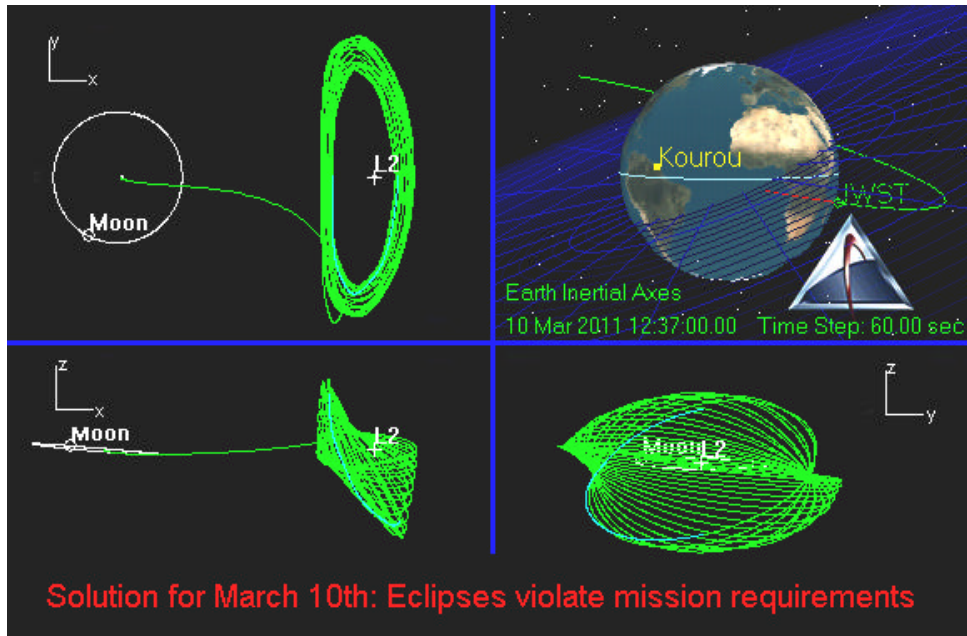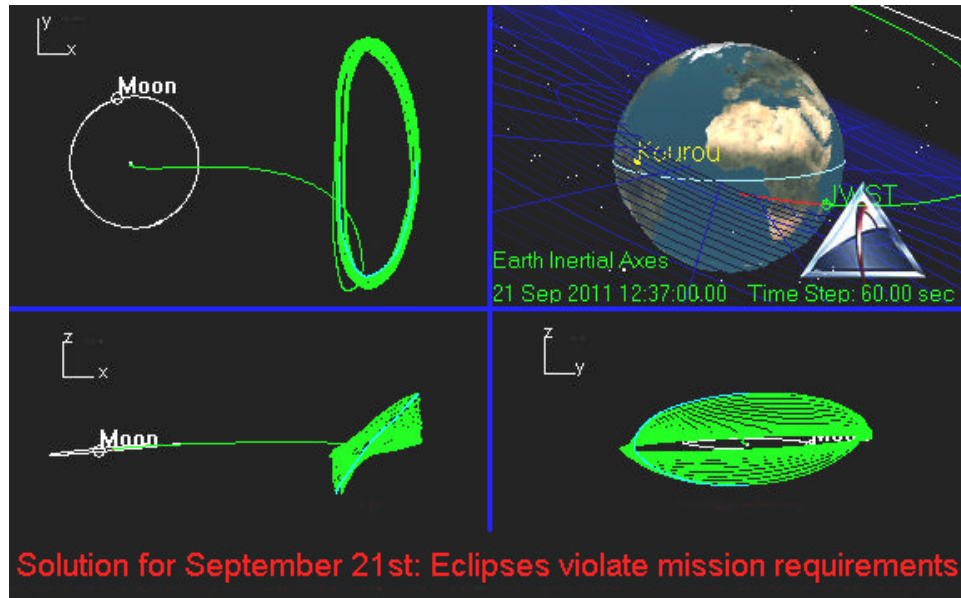

Maximum Z-Amplitude, Year 2011

Maximum Y-Amplitude, Year 2011

Minimum Sun-Earth-Vehicle Angle, Year 2011

Total Mission Eclipse Time, Year 2011

Sample Eclipse Report

Start Time (YYYY/MM/DD)	Stop Time (YYYY/MM/DD)	Duration (hr)	Obstruction
2011/10/06 14:34:47.94	2011/10/08 07:07:50.14	40.551	Earth
2012/01/11 07:31:24.95	2012/01/12 01:44:30.56	18.218	Earth
2012/04/09 02:24:46.18	2012/04/10 06:05:48.60	27.684	Earth
2012/06/29 18:18:33.50	2012/06/30 03:30:54.55	9.206	Moon
2012/07/10 03:31:32.85	2012/07/10 13:45:28.35	10.232	Earth
2012/07/10 13:45:28.35	2012/07/10 14:26:33.50	0.685	Earth
2012/07/10 14:26:33.50	2012/07/11 00:41:39.62	10.252	Earth
2012/10/02 16:06:02.53	2012/10/02 20:08:19.32	4.038	Moon
2012/10/10 07:19:28.82	2012/10/11 08:48:58.42	25.492	Earth
2012/10/17 08:14:18.66	2012/10/17 18:10:32.15	9.937	Moon
2013/01/06 21:52:40.38	2013/01/07 15:05:21.65	17.211	Earth
2013/04/06 06:16:09.63	2013/04/06 19:09:13.97	12.885	Earth
2013/04/12 01:54:48.30	2013/04/12 11:56:59.61	10.036	Moon
2014/06/29 01:08:44.20	2014/06/29 05:10:41.47	4.033	Moon
2014/07/18 07:43:57.60	2014/07/19 02:55:02.37	19.185	Moon
2015/07/11 20:17:34.63	2015/07/11 22:09:03.39	1.858	Moon

Personal Contributions

-wrote code to extend orbit for ten years
-extracted all data from orbits
-ran program, assembled and plotted data

Solution for March 10th: Eclipses violate mission requirements

Solution for July 1st: No eclipses

Solution for September 21st: Eclipses violate mission requirements

Current Conclusions

-Perigee velocity, C3 energy, and apoapsis radius are cyclic with moon cycle and highest when moon is near flight path
-Launches near either vernal or autumnal equinox result in eclipses during mission
-Minimum SEV angle increases when launch moves away from equinoxes
-Highest orbit amplitudes occur during the middle of the year
-January, May, June, July, August, November and December are eclipse-free

Future Work

-Expand launch window: find range of times throughout day that produce acceptable launch